SERDP CU-1074

REPORT

INTERIM REPORT

PERFORMANCE MONITORING OF THE PERMEABLE REACTIVE BARRIER AT DOVER AFB

To

USAF, AFRL/MLQE

Tyndall Air Force Base, Florida

February 22, 1999

20000720 160

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 22, 1999	Interim Report

4. TITLE AND SUBTITLE
Performance Monitoring of the Permeable Reactive Barrier at Dover AFB

5. FUNDING NUMBERS
N/A

6. AUTHOR(S)
Battelle

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Battelle
505 King Avenue, Columbus, Ohio

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
SERDP
901 North Stuart St. Suite 303
Arlington, VA 22203

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release: distribution is unlimited.	A

13. ABSTRACT ***(Maximum 200 Words)***

Based on column tests conducted between February and June 1997, NERL recommended that in terms of effectiveness in achieving cleanup standards and kinetics, a pyrite-iron combination ranked as the best reactive medium (EPA, 1997). Based on this recommendation, in December 1997 Battelle designed and installed a funnel-and-gate type permeable barrier with two gates. Both gates consist of a reactive cell containing granular iron, preceded by a pre-treatment zone (PTZ). The PTZ in Gate 1 consists of a 1% iron-sand mixture; the PTZ in Gate 2 consists of a 10% pyrite-sand mixture. The aim of the PTZ is to improve the longevity of the reactive medium by scrubbing out oxygen from the groundwater before it reaches the 100% iron zone. In the column tests, EPA also reported potential for pH control when pyrite was used. Dissolved oxygen and high pH are detrimental to the longevity of the reactive medium because these conditions promote the formation of precipitates on the granular iron surfaces, thus potentially altering the reactivity and hydraulic performance of the barrier.

14. SUBJECT TERMS	15. NUMBER OF PAGES
SERDP, SERDP Collection, pearmeable reactive barrier, PTZ, pyrite	32
	16. PRICE CODE N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclass	unclass	unclass	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Interim Report

Performance Monitoring of the Permeable Reactive Barrier at Dover AFB

1.0 Project Background

The Air Force Research Laboratory (AFRL), Tyndall Air Force Base (AFB), Florida contracted Battelle, Columbus, Ohio in April 1997 to conduct a demonstration of a pilot-scale field permeable reactive barrier at Area 5, Dover AFB, Delaware. This project is being funded by the Strategic Environmental Research and Development Program (SERDP). The objective of this demonstration is to field-test the performance of two different reactive media in treating dissolved chlorinated solvents in groundwater. The two reactive media were selected by the U.S. Environmental Protection Agency (EPA's) National Exposure Research Laboratory (NERL). NERL was separately funded by SERDP to conduct long-term, above-ground column tests at Area 5 with several different reactive media.

Based on column tests conducted between February and June 1997, NERL recommended that in terms of effectiveness in achieving cleanup standards and kinetics, a pyrite-iron combination ranked as the best reactive medium (EPA, 1997). Based on this recommendation, in December 1997 Battelle designed and installed a funnel-and-gate type permeable barrier with two gates, as shown in Figures 1 and 2 (Battelle, 1997). Both gates consist of a reactive cell containing granular iron, preceded by a pre-treatment zone (PTZ). The PTZ in Gate 1 consists of a 10% iron-sand mixture; the PTZ in Gate 2 consists of a 10% pyrite-sand mixture. The aim of the PTZ is to improve the longevity of the reactive medium by scrubbing out oxygen from the groundwater before it reaches the 100% iron zone. In the column tests, EPA also reported potential for pH control when pyrite was used. Dissolved oxygen and high pH are detrimental to the longevity of the reactive medium because these conditions promote the formation of precipitates on the granular iron surfaces, thus potentially altering the reactivity and hydraulic performance of the barrier.

The aquitard at Area 5, Dover AFB, is around 40 ft deep, a depth at which conventional excavation with a standard backhoe is not efficient. Therefore, an innovative installation technique involving the use of caissons was implemented to install the two gates. When this technique was used at one previous site (Sommersworth Landfill Site, New Hampshire), it ran into a number of installation and operation problems. However, after lessons learned at the previous site, the caisson-based technique was used at Dover without any apparent problems. Therefore, the Dover demonstration represents both a test of an alternative reactive medium and an alternative construction technique.

The barrier performance was monitored over the last year. Some hydraulic performance parameters, such as water levels and groundwater flow velocity and direction, were monitored frequently for the first six months after installation. When flow through the barrier appeared to have stabilized, more comprehensive monitoring of the barrier was conducted in July 1998. Another small monitoring event involving a few key wells was conducted in December 1998. The monitoring conducted so far suggests that the barrier is performing as designed.

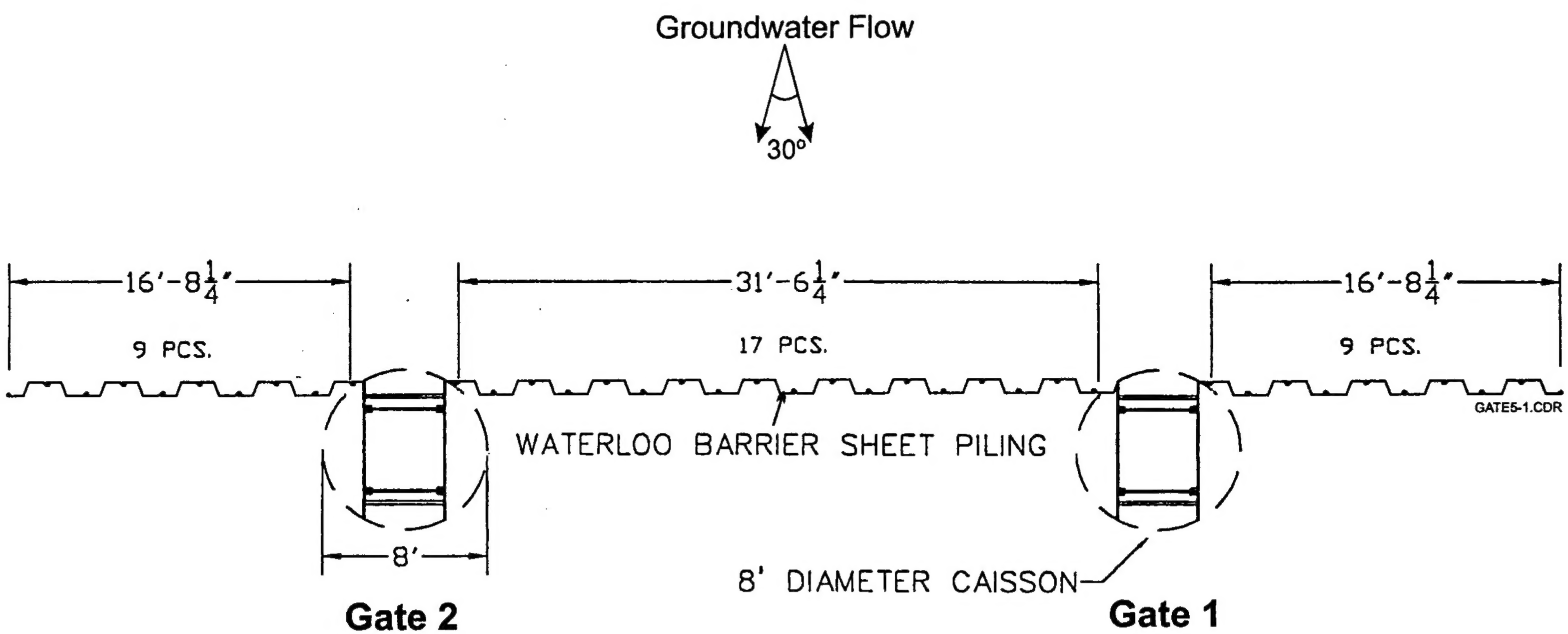
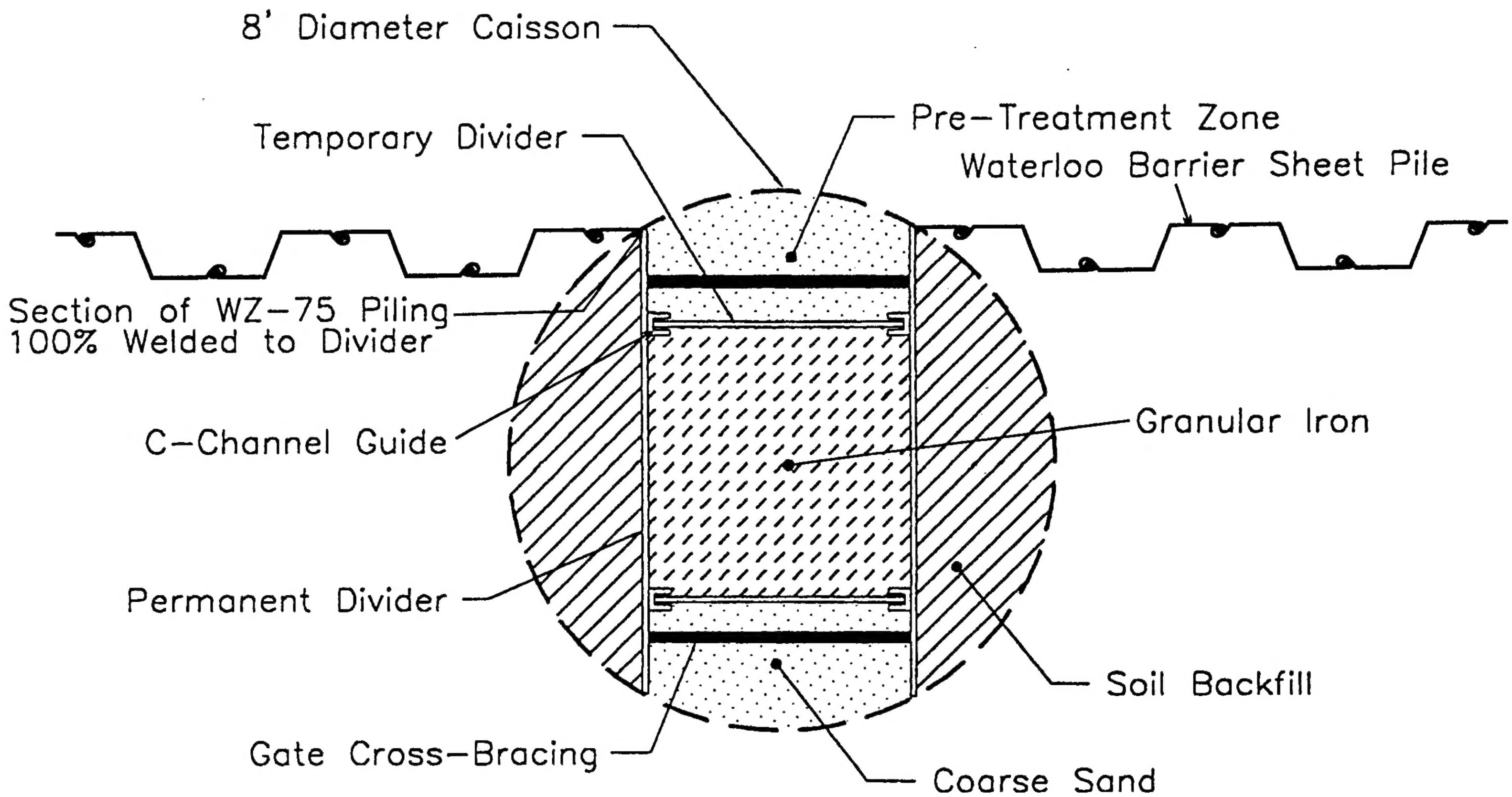


Figure 1. Permeable Barrier Plan View at Dover AFB, Dover, Delaware (Based on C³ Environmental drawing; modified by Battelle)



GATE5-2.CDR

Figure 2. Permeable Barrier Gate Detail at Dover AFB, Dover, Delaware (Based on C[3] Environmental drawing; modified by Battelle)

2.0 Site Description

Figure 3 shows a geological cross section at the Area 5 site. The water table occurs at approximately 15 ft bgs. The clay aquitard occurs at approximately 40 ft bgs. There is a thin, intermediate, fine-grained layer at around 15 ft. The aquifer consists of mostly sandy soil. Figure 4 shows the plume as it was delineated during site characterization in June 1997. The barrier was installed near the driveway of the parking lot near Building 639 in an effort to capture the more contaminated portions of the plume. The plume contains the chlorinated volatile organic compounds (VOCs) perchloroethylene (PCE), trichloroethylene (TCE), and *cis*-1,2 dichloroethylene (DCE). No significant non-chlorinated VOC compounds were found in the groundwater at Area 5. The groundwater flow is to the southwest and VOCs concentrations decrease with distance from the building. The VOC concentrations also vary by depth and were found in both shallow and deep regions of the aquifer. The highest concentration found in June 1997 was 5,617 µg/L of PCE. The groundwater gradient in the parking lot is relatively flat and groundwater velocities are relatively low (less than 0.1 ft/day).

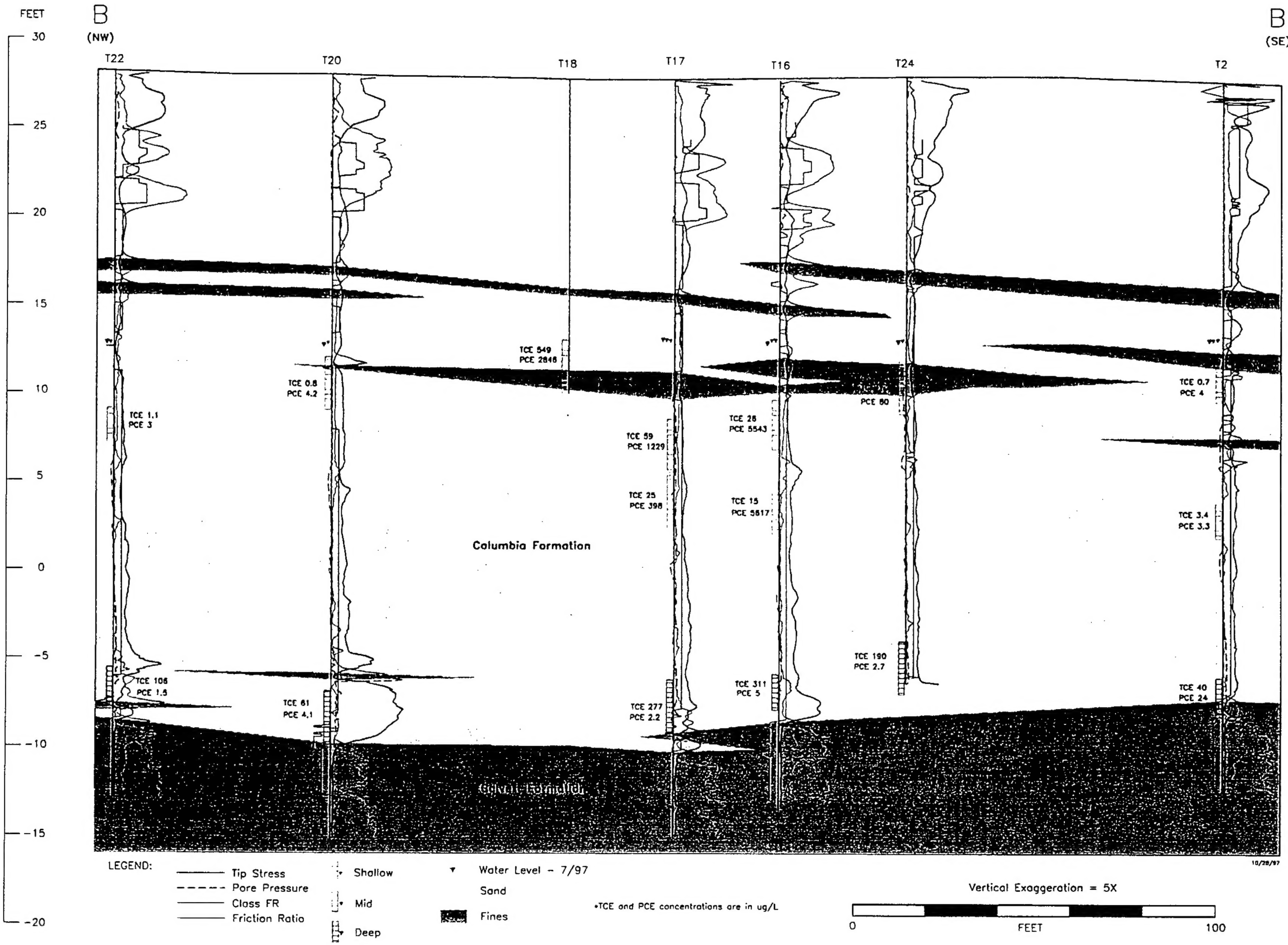


Figure 3. Geological Cross Section Near the Permeable Barrier at Area 5

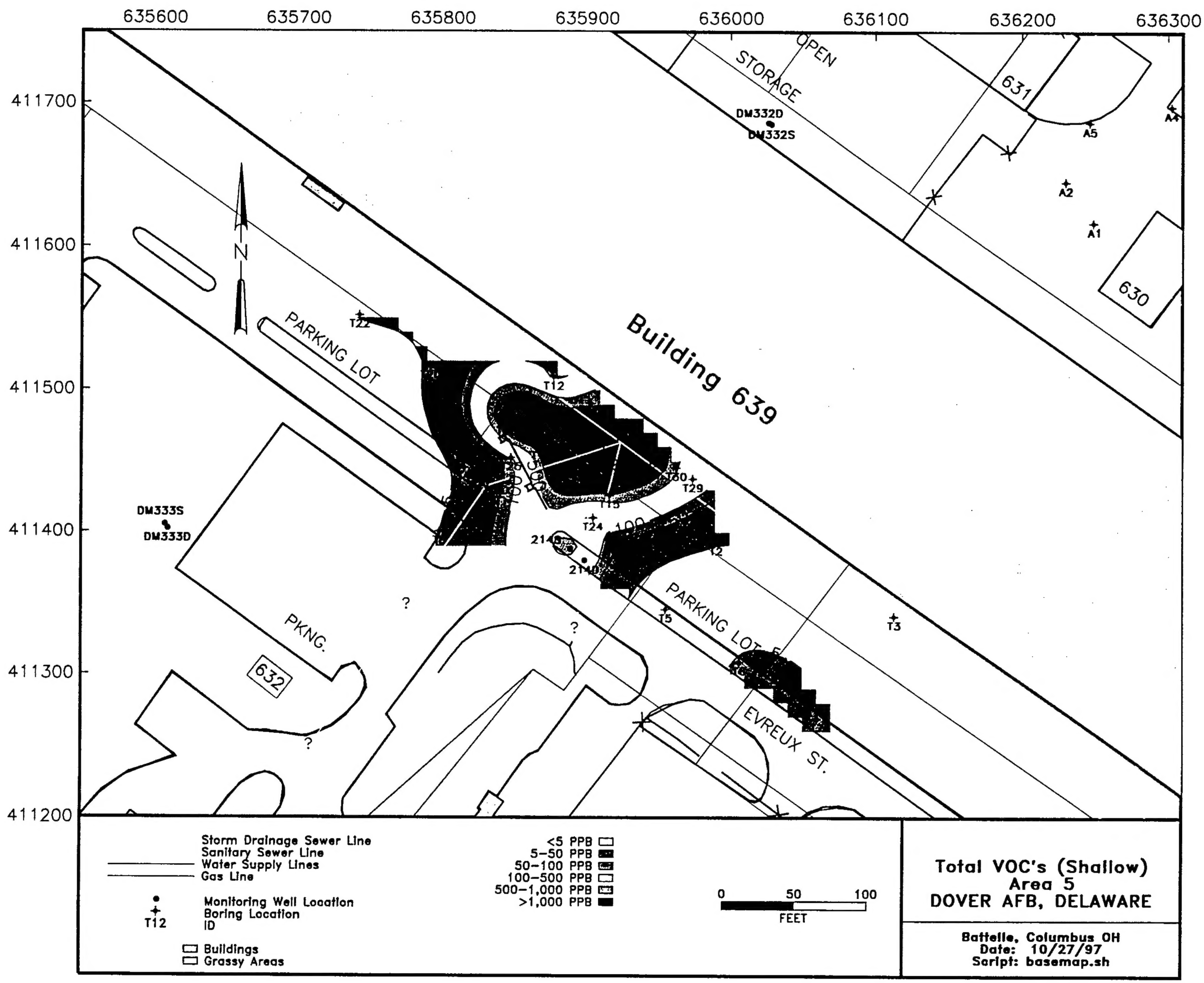


Figure 4. Plume and Permeable Barrier Location in the Area 5 Parking Lot

3.0 Barrier Design and Construction

Figure 4 (Section 2) shows the location of the permeable barrier in relation to the chlorinated VOCs plume. The barrier was oriented perpendicular to the expected groundwater flow direction after taking into account a 30-degree seasonal variation. To obtain maximum information from the demonstration, the barrier was located within the plume boundary. The target region contains a number of underground utility lines, and this was another factor in the selection of the construction technique. Figure 1 (Section 1) shows the entire barrier and Figure 2 (Section 1) shows a close-up view of Gate 1, which incorporates a PTZ of 10% iron-sand mixture. Gate 2 incorporates a 10% pyrite-sand mixture. The gates are 4 ft wide and were installed using an 8-foot-diameter circular caisson. The funnel is approximately 60 ft wide with a 30-foot section between the two gates and two 15-foot sections on the wings.

Figures 5 and 6 also show the locations of the monitoring wells installed in the gates and in the barrier vicinity. Wells are designated as S, M, or D depending on whether they are screened at shallow, medium, or deep levels in the aquifer. The arrangement of the upgradient aquifer wells is designed to allow hydraulic measurements to be conducted. Four Sandia water velocity meters were installed, one in each gate and two in the upgradient aquifer. The objective was to measure the direction and velocity of the groundwater as it approaches the barrier and flows through the gates.

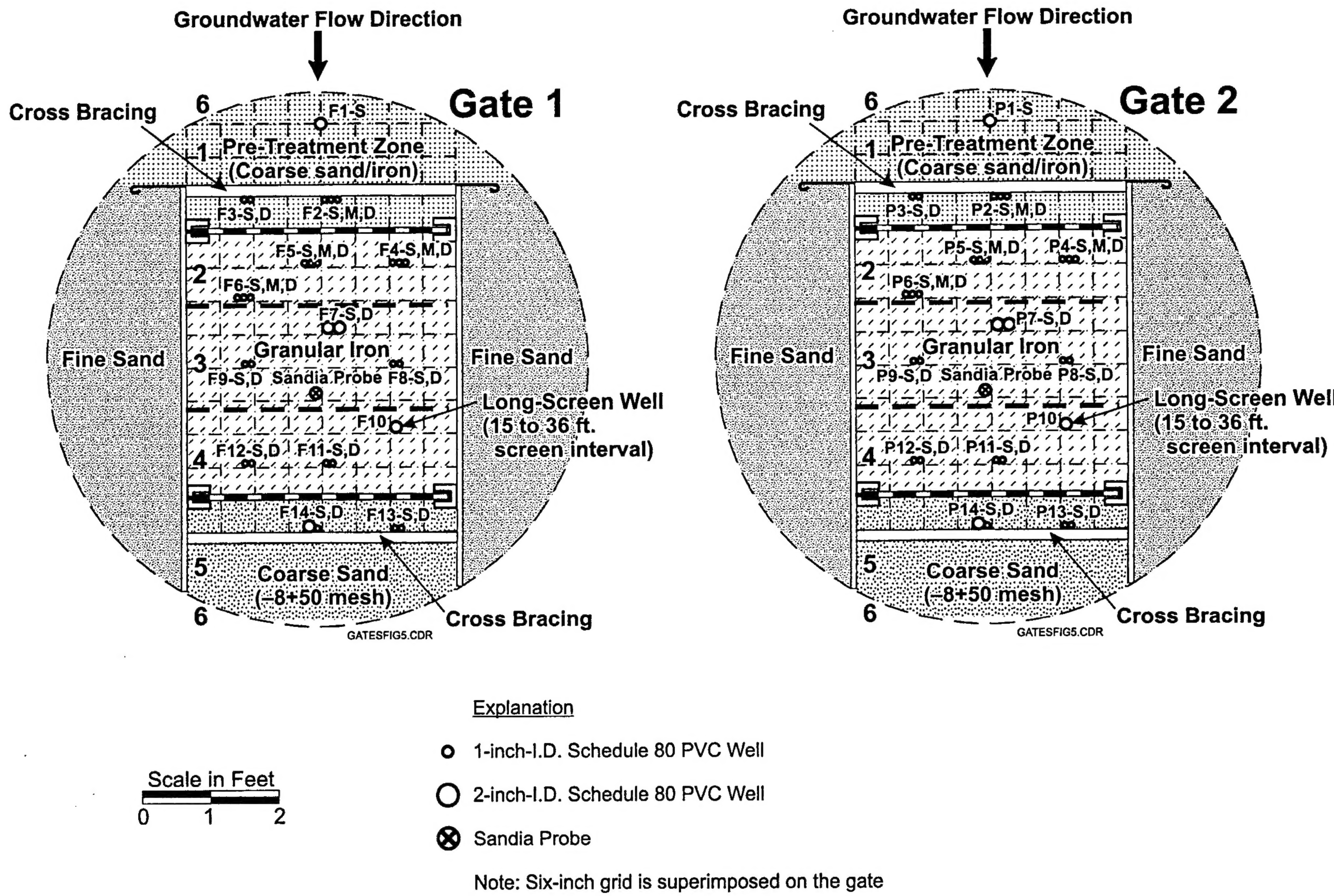


Figure 5. Monitoring Point Network Within Gates 1 and 2

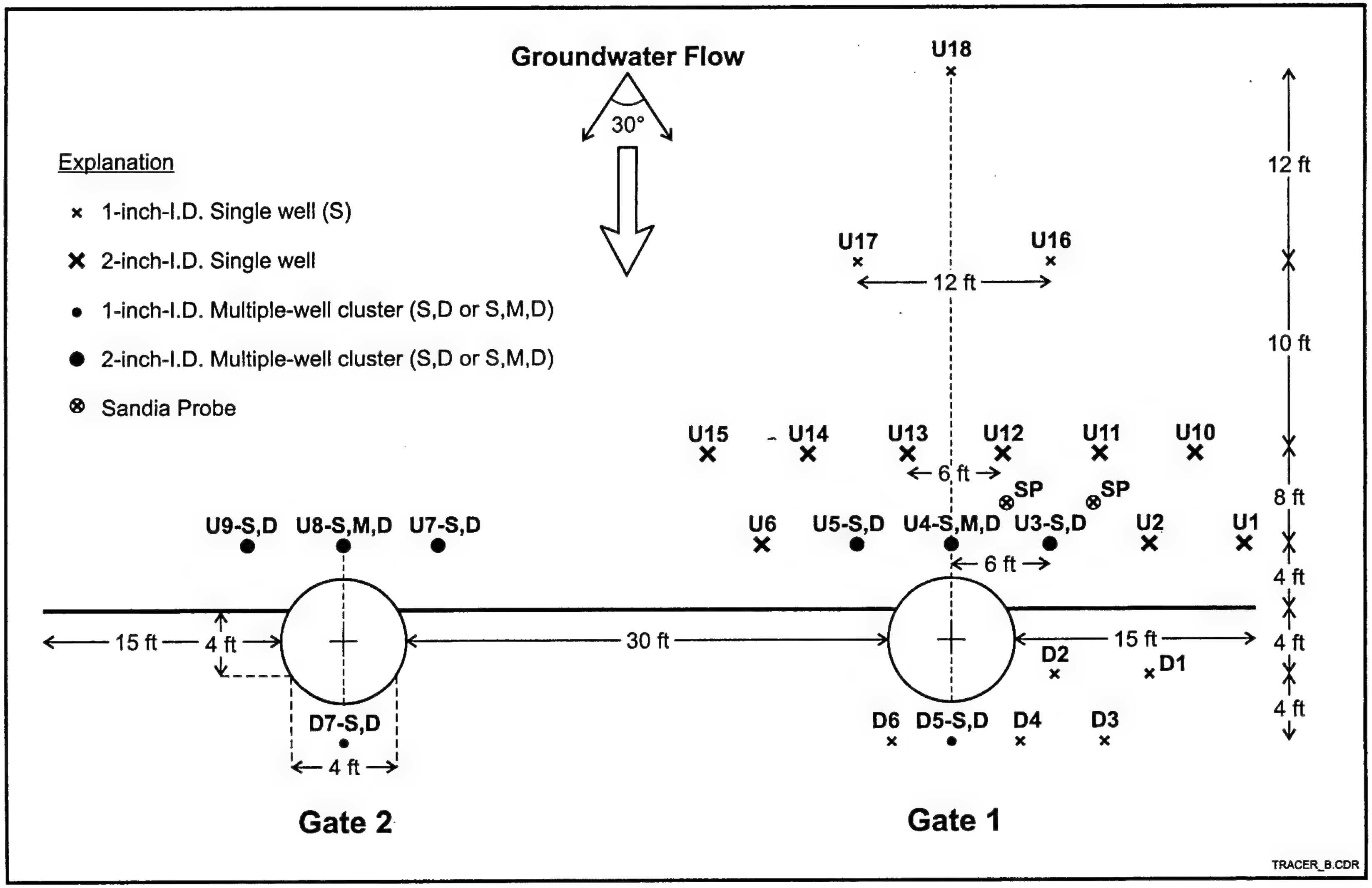


Figure 6. Monitoring Well Network in Aquifer

4.0 Performance Monitoring

Appendix A contains detailed monitoring data for the Dover barrier. A summary of these data is used below to highlight performance-related trends of interest.

4.1 Contaminant Destruction and Geochemistry

Table 1 summarizes data from selected wells along the flow paths through the two gates at the Dover permeable barrier. Although chlorinated-VOC concentrations entering the barrier are lower than previously expected, the following observations suggest that the permeable reactive barrier is operating as designed:

- Decline in PCE, TCE, and DCE concentrations along the flow path.
- Decline in dissolved oxygen (DO) and Eh along the flow paths, indicating a strong reducing environment in the gates.
- Increase in pH along the flow path, indicating generation of OH^- ions as the VOCs and DO react with the iron.

The rebound in some of these parameters as the water leaves the gates (in the post-treatment zones and downgradient aquifer) indicate some re-mixing with contaminated water on the downgradient side of the barrier. As time progresses, a clean front can be expected to emerge on the downgradient side (wells D5D and D7D), an effect that we observed after about two years of operation of the Moffett Field barrier.

Some differences in the pH responses of the two pre-treatment zones (PTZs) were anticipated, indicating that the pyrite controls pH better than the iron. However, no significant differences in pH are obvious in the field data. This could be due to several reasons:

- The groundwater flow is too slow to highlight any differences in pH control over the short flowpath through the PTZ.

- The reaction rate of the pyrite with DO is too low.

- Some backflushing of groundwater from the iron cell (as may temporarily occur) after high-rainfall events may be masking the pH-control action of the pyrite. As seen from Eh readings, the Eh in Gate2 (pyrite) PTZ does not drop as rapidly as in Gate 1 PTZ, indicating that iron is more reducing than pyrite (as expected). However, Eh is more sensitive to changes in the incoming water, whereas pH may be more resilient due to buffering effects. This could change as the flow through the gates stabilizes still further.

Inorganic parameters (Table 2) measured in the Area 5 groundwater also show expected trends. Magnesium and alkalinity (bicarbonate) concentrations decrease along the flow direction through the gates. This indicates formation of precipitates in the iron zone. Depending on the size of the precipitate particles, they could either be retained in the iron zone or transported out with the groundwater flow. Nitrate is reduced in the iron zone, as expected. The trends with calcium and sulfate are not as clear.

Table 1. July and December 1998 VOC and Field Parameter Data Summary

Wells	PCE Jul-98	(ug/L) Dec-98	TCE Jul-98	(ug/L) Dec-98	c-DCE Jul-98	(ug/L) Dec-98	DO(mg/L) Jul-98	Eh(mV) Jul-98	pH Jul-98
Gate 1									
Upgr.Aquifer									
U3D	273	140	16	13	35	40	1.4	229	4.6
U4M	300		21		62		6.1	263	4.6
U4D	334	390	22	42	69	140	5.3	269	4.7
U5D	155		11		20		0.9	270	5.5
PTZ									
F2D	ND		ND		ND		<0.5	-250	10.2
Iron									
F5D	ND	ND	ND	ND	ND	ND	<0.5	-296	10.7
F7D	7		6		ND		<0.5	-285	10.7
F11D	ND		ND		ND		0.5	-271	10.6
Post-Tr.Zone									
F14D	ND		ND		ND		0.9	-287	10.5
Downgr.Aquifer									
D5D	110		ND		ND		0.6	126.7	5.9
Gate 2									
Upgr. Aquifer									
U7D	47	84	9	10	6	22	0.7	271	5.2
U8M	150		15		14		0.5	198	6.3
U8D	139	76	18	5	15	10	0.9	169	6.1
U9D	275		21		52		3.6	292	4.7
PTZ									
P2D	ND		6		ND		<0.5	-183	10.7
Iron									
P5D	ND	12	ND	ND	ND	ND	<0.5	-253	10.9
P7D	ND		ND		ND		<0.5	-228	11
P11D	ND		ND		ND		<0.5	-228	11.1
Post Tr.Zone									
P14D	ND		ND		ND		<0.5	-183	10.6
Downgr.Aquifer									
D7D	ND		ND		9		<0.5	-6	9.8

Table 2. July 1998 Inorganics Data Summary

Wells	Ca (mg/L)	Mg (mg/L)	Alkalinity (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)
Gate 1					
Upgradient Aquifer					
U3D	NA	NA	NA	NA	NA
U4M	NA	NA	NA	NA	NA
U4D	4.9	4.8	4	12	11
U5D	NA	NA	NA	NA	NA
Pre-Treatment Zone					
F2D	3.43	0.48	46	<5	0.08
Iron Cell					
F5D	5.2	<0.2	29	15	<0.02
F7D	7.5	<0.2	35	24	<0.02
F11D	10.3	<0.2	53	19	<0.02
Post-Treatment Zone					
F14D	6	<0.2	36	22	<0.02
Downgradient Aquifer					
D5D	6.2	1.16	28	24	0.16
Gate 2					
Upgradient Aquifer					
U7D	NA	NA	NA	NA	NA
U8M	NA	NA	NA	NA	NA
U8D	9.2	4.99	54	61	2.89
U9D	NA	NA	NA	NA	NA
Pre-Treatment Zone					
P2D	8.9	<0.2	42	53	<0.02
Iron Cell					
P5D	3.37	<0.2	79	21	0.03
P7D	4.25	<0.2	81	29	<0.02
P11D	45.7	<0.2	75	37	<0.02
Post Treatment Zone					
P14D	4.65	<0.2	92	23	<0.02
Downgradient Aquifer					
D7D	5.3	<0.2	112	8	<0.02

4.2 Hydraulic Performance

Evaluation of the hydraulic performance of the system includes the characterization of media using slug tests and laboratory tests; monitoring of periodic and continuous water levels; and monitoring of velocity using in-situ (HydroTechnics™) and in-well (K-V meter) probes. The overall objectives of the monitoring are to observe and quantify the capture zone and the flow through the reactive barrier. Selected results from the hydraulic monitoring are presented here.

Slug tests are simple hydraulic tests that provide an estimate of hydraulic conductivity (K) around a well screen. Duplicate slug tests were performed in 27 wells in and around the reactive gates. Tests in aquifer wells ranged from 1.8 ft/day to 101 ft/day with higher K in deeper wells. As a comparison, slug tests conducted in the older monitoring wells near the reactive barrier had shown a range of 1 to 11 ft/day. Tests in the reactive gates showed much higher K, ranging from 124 ft/day to 2,486 ft/day.

Samples of the reactive iron, pyrite, and sand were sent to a laboratory for determination of porosity, grain-size distribution, and K. The sieve analyses for grain size distribution showed that the sand, iron, sand + 10% iron, and sand + 10% pyrite mixtures ranged from coarse to very coarse grain size (mostly between sieves #40 and #10). The respective porosity values of sand, iron, sand + 10% iron, and sand + 10% pyrite were 0.37, 0.62, 0.36, and 0.32. The respective K values of sand, iron, sand + 10% iron, and sand + 10% pyrite were 1,900, 850, 1,560, and 1,304 ft/day, respectively. These values and the slug test results in the reactive barrier wells show that the K values in the reactive media can be much higher than previously used values of about 150 to 300 ft/day.

The water levels at the reactive barrier have been monitored since the construction. The periodic water levels have been monitored to observe long-term changes in flow conditions at the site. The continuous water levels were monitored during 1998 to determine the extent of short-lived water level fluctuations. The database for periodic water level measurements includes 95 monitoring wells inside and in the vicinity of the reactive barrier and 20 preexisting background wells at Dover AFB. The periodic water levels have been measured 16 times in these wells so far in the reactive barrier wells and 6 times in the existing Base wells. An example of the seasonal water level changes in five wells along a possible flow path in Gate 1 shown in Figure 7. As expected, the water levels are the highest during spring months and recede during summer and fall. During 1998 the seasonal fluctuation in water level was about 5 ft. The site-wide water levels from individual monitoring events can also be contoured to evaluate the flow patterns in the vicinity of the funnel-and-gate system. Figures 8 shows water levels in shallow wells during February 1998. As seen in this map, the flow vectors point towards the two gates, indicating that groundwater is being captured by the gates as designed. Maps prepared for the other monitoring events do not show the capture as clearly as Figure 8, however, the overall flow vectors still converge towards the gates. It is difficult to construct contour maps for water levels inside the gates because the short distances result in measurement errors that may be greater than the actual water level differences. In general however, differences in water levels observed in the upgradient aquifer, pretreatment zones, reactive cells, PTZs, and downgradient aquifer are driven by differences in K values. High K values in the reactive media result in a very flat hydraulic gradient, even when there is significant flow through the gate.

Continuous in situ monitoring was performed using TROLL™ SP4000 downhole water level probes. Hourly measurements were recorded at strategic locations along suspected groundwater flowpaths through each of the gates for durations ranging up to several weeks. An example of the

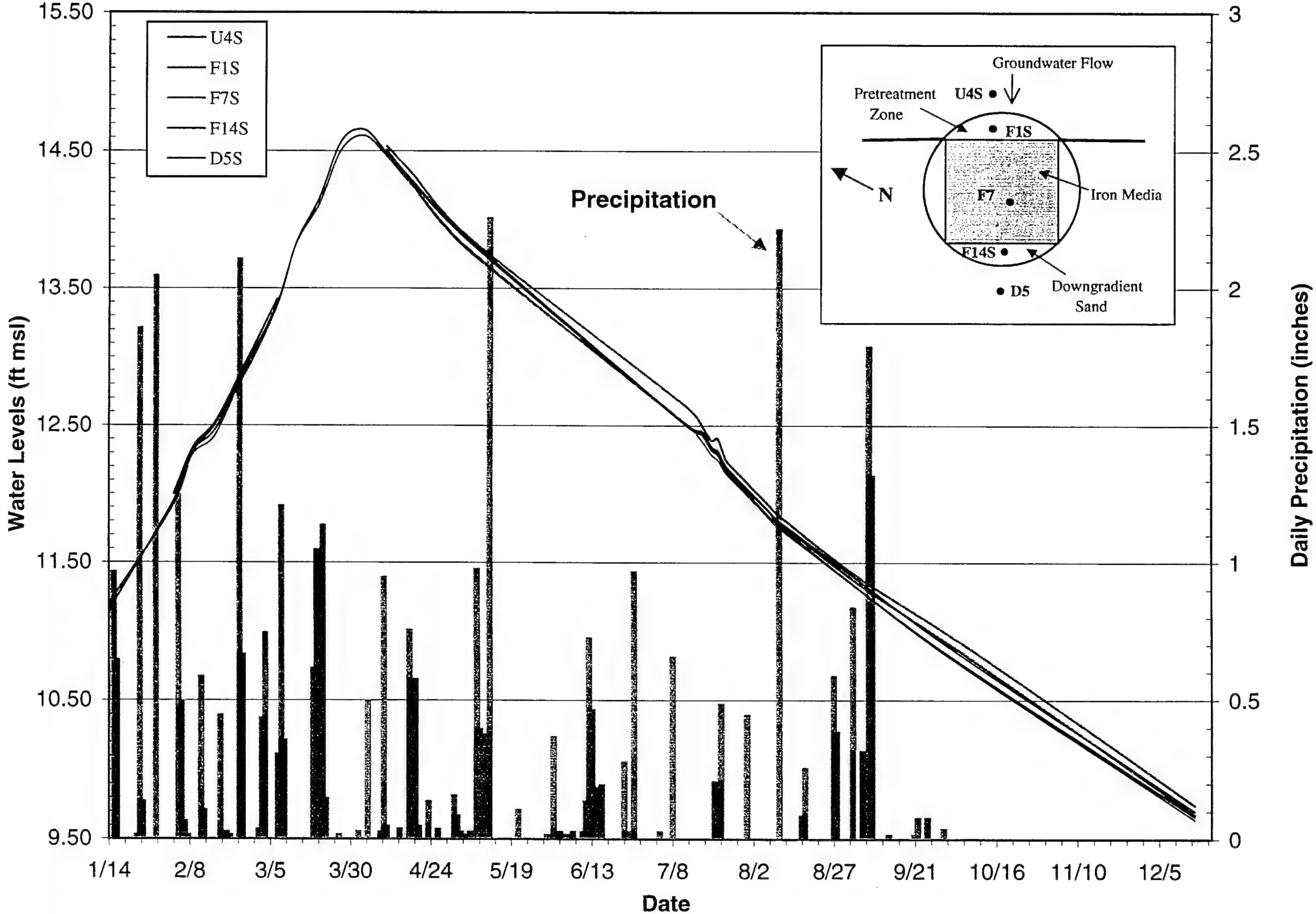


Figure 7. Periodic Water Level Measurements and Rainfall

Water Levels (shallow) Feb 03, 1998 - Area 5 Funnel and Gate, Dover AFB

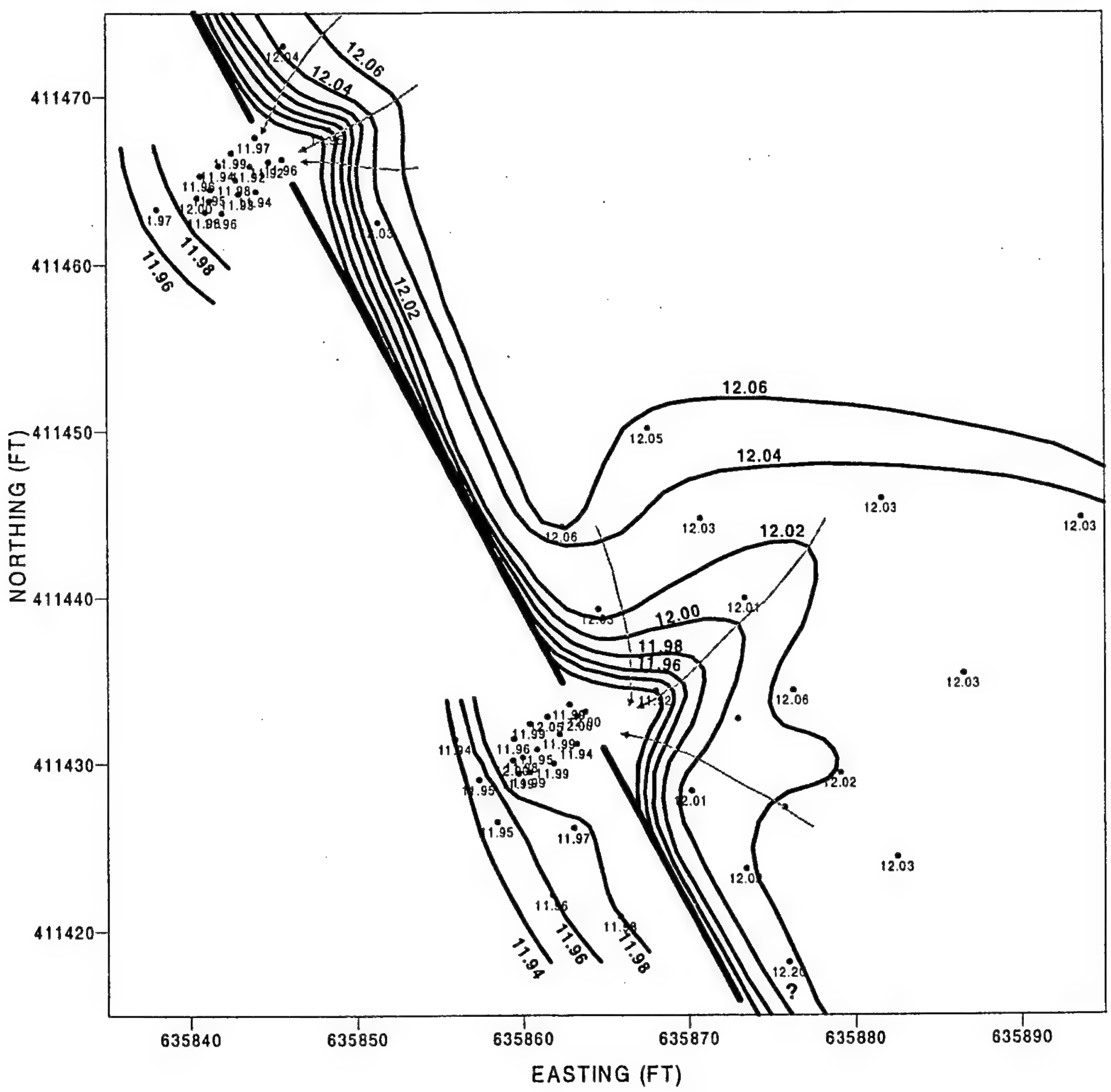


Figure 8. Flow Through the Gates as Indicated by Water Levels

water levels in four wells at Gate 2 is shown in Figure 9. Water levels decrease abruptly from the aquifer to the reactive cells, indicating that flow is taking place into the reactive cell. However, the water levels in the downgradient post treatment zone (Well P14S) appear to be slightly higher than in the iron cell well and upgradient pretreatment zone. This is most likely due to the sharp K contrasts across these zones. While it indicates that there may be some stagnation in the cell, a backflow in the cell is still not likely, because the water levels in the downgradient aquifer are still lower than in the upgradient aquifer.

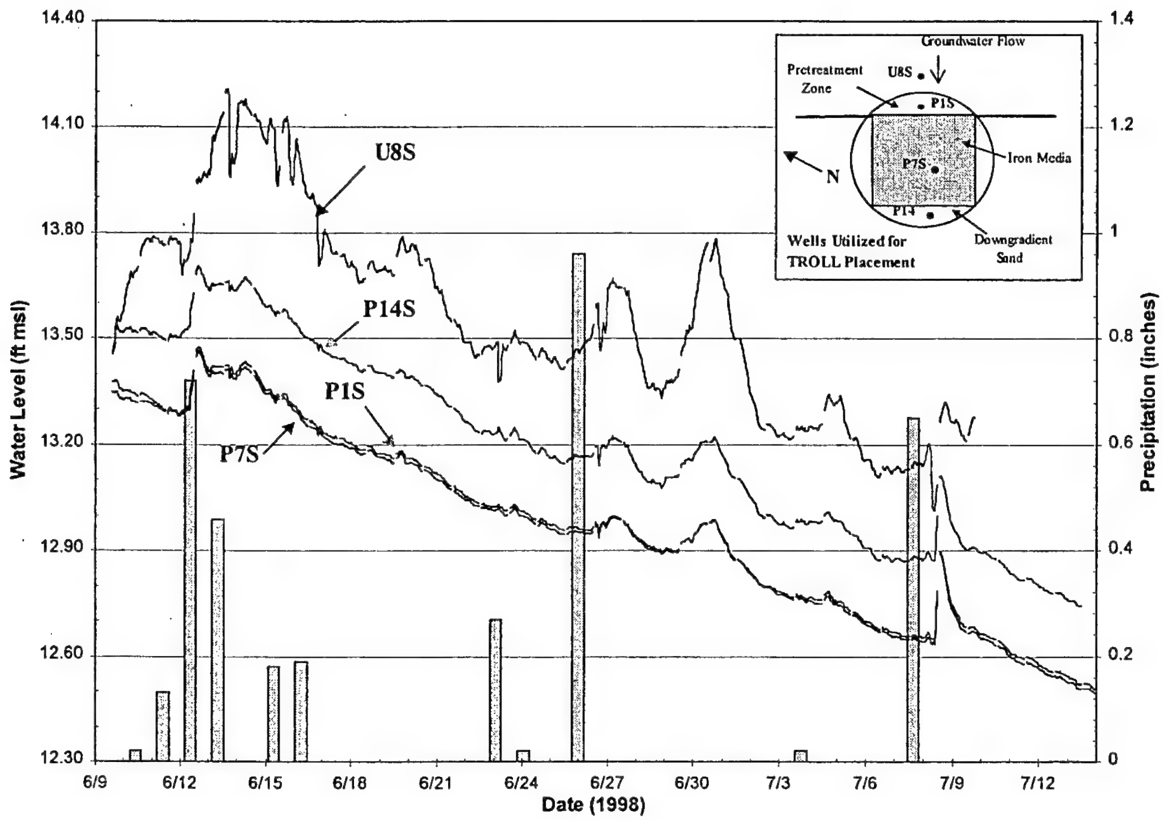
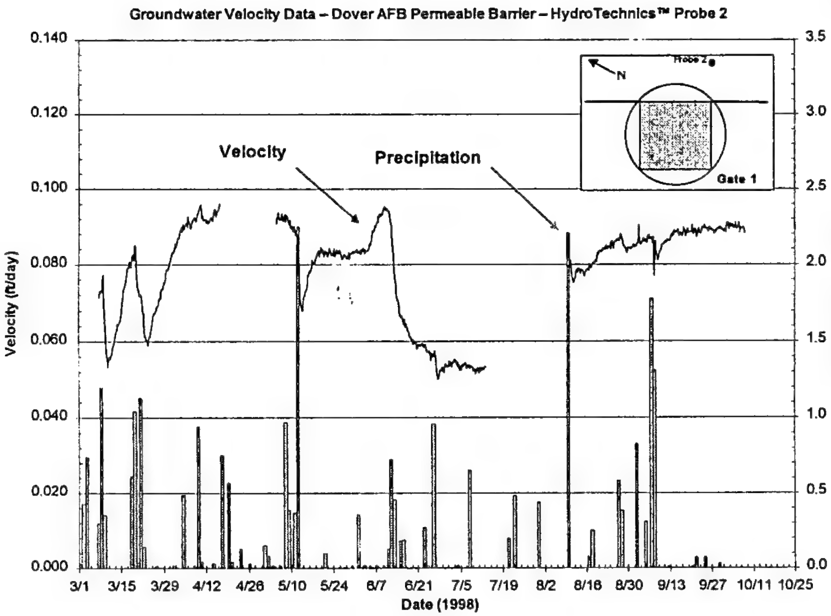
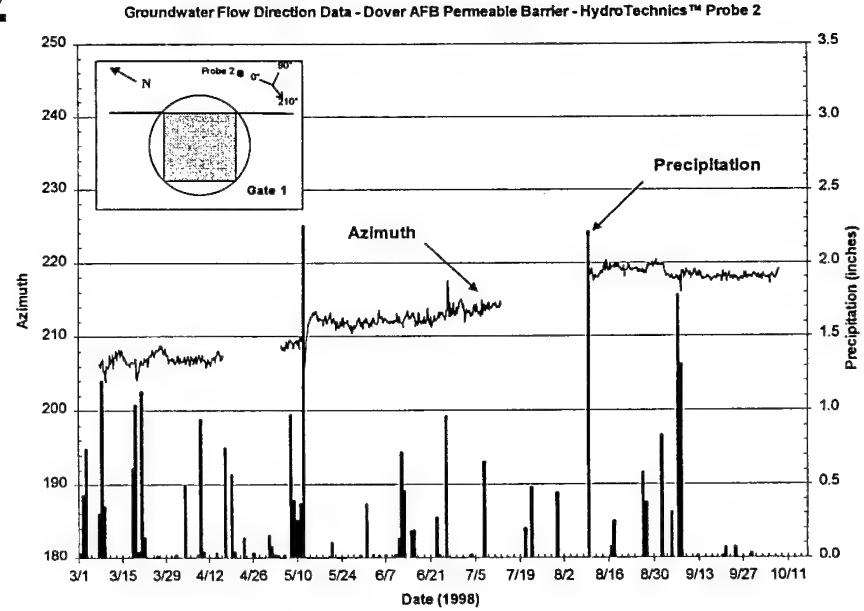


Figure 9. Continuous Water Level in Area 5 Aquifer and Rainfall

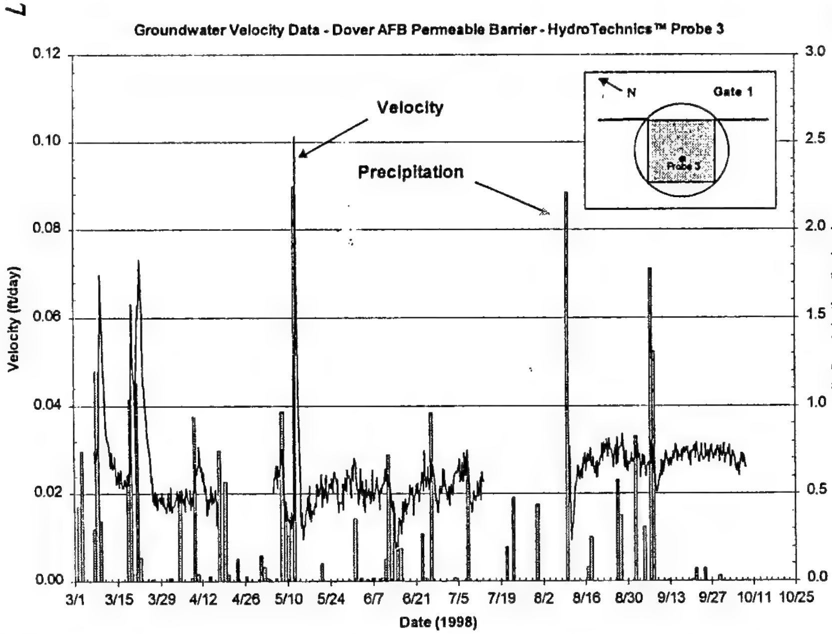
HydroTechnics™ groundwater velocity and direction sensors were installed in the aquifer upgradient of Gate 1 (Probes 1 and 2), in the iron section of Gate 1 (Probe 3), and in the iron section of Gate 2 (Probe 4). These direct-bury sensors have been collecting data continuously at half-hour intervals since March 1998. The velocity and flow direction results from Probes 2 and 3 are shown on Figure 10. Groundwater velocities in the upgradient aquifer near Gate 1 range from 0.03 ft/day at Probe 1 to 0.08 ft/d at Probe 2. After an initial adjustment period, directional measurements (azimuth) have stabilized toward the south to southwest. Groundwater velocities in both reactive cells are typically 0.03 ft/day. Velocities in both gates fluctuate rapidly in response to rainfall events. Groundwater flow directions within the reactive cells have changed steadily over time since construction, from an initial northwesterly direction to a southwesterly

Probe 2





Probe 3



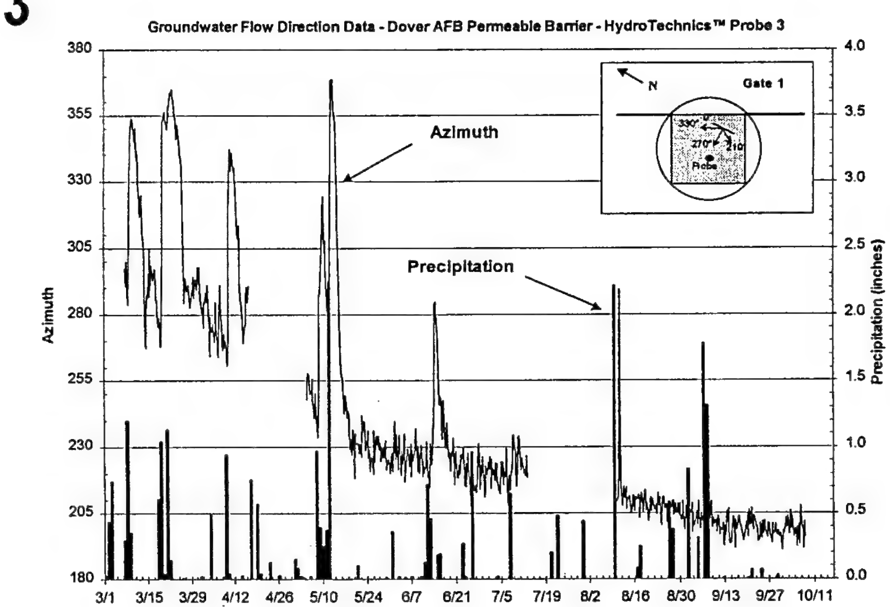


Figure 10. Groundwater Flow Velocity Measurements in Aquifer (Probe 2) and in Gate 1 (Probe 3)

direction during the summer months. Measurements collected in recent months indicate that groundwater is flowing directly through each of the gates. Some measurements were also taken using the K-V meter in-well velocity probe. However, the results from this probe appear to be inconsistent and unreliable.

Overall, based on the observations so far, the reactive barrier appears to be performing as designed. The flow is occurring through both gates and a clear capture zone can be defined. However, the seasonal fluctuations in water levels and sharp K contrasts over short distances make is difficult to make consistent capture zone and velocity estimates. More consistent estimates may be possible in future as the system stabilizes further.

5.0 Conclusions and Recommendations

Monitoring done to date indicates that the permeable reactive barrier at Area 5, Dover AFB is performing as designed in terms of contaminant destruction, control of inorganic constituents build up, and hydraulic flow.

During site characterization in June 1997, VOCs were observed in both shallow and deep portions of the aquifer, with somewhat higher concentrations in the shallow regions. During the July 1998 and December 1998 sampling events, VOCs were observed consistently in the deep wells (as seen in Table 1 and Appendix A), but only occasionally in the shallow wells. Some possible reasons for this are as follows:

- In June 1997, the site was at peak water level conditions, as compared to July 1998 or December 1998. A lower water table in the recent two monitoring events could have led to reduced (or no) contact of the groundwater with any perched DNAPL in the intermediate (15 ft bgs) clay layer. This could affect downstream VOC concentrations. Also, historically, water level changes have caused water flow direction to change by as much as 30-degrees at Area 5, thus affecting plume movement.

- Differences in size and depth of well screens between the temporary cone penetrometer test (CPT) wells used for site characterization (3-foot screens, 19 to 22 ft bgs) and the permeable barrier monitoring wells (5-foot screens, 15 to 20 ft bgs) could be affecting measured concentrations. Longer screens were used in the barrier monitoring wells to obtain better depth coverage with fewer wells.

- The shallow plume has yet to reach the barrier. Because some underground utilities were uncovered during construction at locations different from those shown on historical site maps, an on-the spot field decision was made to move the barrier about 8 feet further downgradient from the designed location. With the groundwater moving at the rate of around 0.05 ft/day (and the plume probably moving even slower), the higher concentrations could still be moving towards the gates.

Although the VOCs currently entering the barrier are at sufficiently high concentrations (60 to 70 times above their respective drinking water limits) to indicate the effectiveness of the barrier, higher concentrations would make it easier to compare any differences in the performance of the two gates (and two media). In order to address these issues, Battelle and AFRL plan to take the following approach:

- One or two more mini-sampling events (in late February and mid-April) will be conducted to measure water levels and sample groundwater (just for PCE, TCE, and DCE) from a few select wells to monitor influent VOC concentrations.

- A second comprehensive monitoring event (possibly in May) will be conducted when higher water level conditions are expected.

In general, monitoring conducted so far shows satisfactory performance trends and future monitoring is expected to consolidate the conclusions regarding the permeable reactive barrier performance at Dover AFB.

6.0 References

Battelle, 1997. Design/Test Plan: Permeable Barrier Demonstration at Area 5, Dover AFB. Prepared for Air Force Research Laboratory, Tyndall AFB, Florida, by Battelle, Columbus, Ohio.

U.S. EPA, 1997. Selection of Media for the Dover AFB Field Demonstration of Permeable Barriers to Treat Groundwater Contaminated with Chlorinated Solvents. Preliminary Report to U.S. Air Force for SERDP Project 107, August 4.

APPENDIX A

Results of July 1998 Comprehensive Monitoring of Dover AFB Permeable Barrier

Table A-1. Results of July 1998 Sampling at Dover Funnel & Gate Site: Organic Analytes, Chlorinated Solvents ($\mu g/L$) (Battelle Results-Draft)

Well ID	*cis*-1,2-DCE Results	*cis*-1,2-DCE Detection Limit	TCE Results	TCE Detection Limit	PCE Results	PCE Detection Limit
Gate 1 Side Upgradient Aquifer Wells						
U1S	U	5	U	5	3 J	5
U2S	U	5	U	5	3 J	5
U3S	U	5	U	5	3 J	5
U3D	35	5	16	5	273	5
U4S	U	5	U	5	2 J	5
U4M	62	5	21	5	300	5
U4D	69	5	22	5	334	5
U5S	U	5	1 J	5	2 J	5
U5D	20	5	11	5	155	5
U6S	U	5	U	5	2 J	5
U6S-DUP	U	5	U	5	1 J	5
U10S	U	5	U	5	4 J	5
U11S	U	5	U	5	3 J	5
U12S	U	5	U	5	3 J	5
U12S-DUP	U	5	U	5	3 J	5
U13S	U	5	U	5	3 J	5
U14S	U	5	U	5	2 J	5
U15S	U	5	1 J	5	5 J	5
U16S	U	5	U	5	9	5
U17S	U	5	U	5	5 J	5
U18S	U	5	U	5	7	5
Gate 1 Wells						
F1S	U	5	2 J	5	3 J	5
F2S	U	5	U	5	2 J	5
F2M	U	5	1 J	5	1 J	5
F2D	2 J	5	U	5	1 J	5
F3S	U	5	U	5	U	5
F3D	1 J	5	U	5	1 J	5
F4S	U	5	1 J	5	2 J	5
F4M	1 J	5	4 J	5	6 J	5
F4D	U	5	1 J	5	2 J	5
F5S	U	5	U	5	2 J	5
F5M	U	5	U	5	U	5
F5D	U	5	U	5	U	5
F6S	U	5	1 J	5	3 J	5
F6M	U	5	1 J	5	1 J	5
F6D	U	5	1 J	5	3 J	5
F6D-DUP	U	5	2 J	5	4 J	5
F7S	U	5	U	5	1 J	5
F7D	5 J	5	6	5	7	5
F8S	U	5	U	5	U	5
F8D	U	5	1 J	5	2 J	5
F9S	U	5	2 J	5	2 J	5
F9D	U	5	2 J	5	3 J	5

Table A-1. Results of July 1998 Sampling at Dover Funnel & Gate Site: Organic Analytes, Chlorinated Solvents (μg/L) (Battelle Results-Draft) (Continued)

Well ID	*cis*-1,2-DCE Results	*cis*-1,2-DCE Detection Limit	TCE Results	TCE Detection Limit	PCE Results	PCE Detection Limit
F10	U	5	1 J	5	2 J	5
F10-DUP	U	5	1 J	5	2 J	5
F11S	U	5	U	5	1 J	5
F11D	U	5	1 J	5	2 J	5
F12S	U	5	U	5	U	5
F12D	U	5	2 J	5	U	5
F12D-DUP	2 J	5	3 J	5	4 J	5
F13S	U	5	1 J	5	3 J	5
F13D	U	5	1 J	5	2 J	5
F14S	U	5	U	5	U	5
F14D	U	5	U	5	2 J	5
Gate 1 Side Downgradient Aquifer Wells						
D1S	1 J	5	2 J	5	4 J	5
D2S	U	5	1 J	5	3 J	5
D3S	U	5	1 J	5	2 J	5
D4S	U	5	U	5	3 J	5
D4S-DUP	U	5	1 J	5	5 J	5
D5S	U	5	U	5	6	5
D5D	2 J	5	3 J	5	110	5
D6S	U	5	U	5	2 J	5
Gate 2 Side Upgradient Aquifer Wells						
U7S	1 J	5	3 J	5	3 J	5
U7D	6	5	9	5	47	5
U8S	U	5	3 J	5	3 J	5
U8M	14	5	15	5	150	5
U8D	15	5	18	5	139	5
U9S	U	5	45	5	4 J	5
U9D	52	5	21	5	275	5
P1S	U	5	4 J	5	3 J	5
P2S	U	5	1 J	5	2 J	5
P2M	U	5	2 J	5	U	5
P2D-1	U	5	6	5	1 J	5
P2D-2	U	5	7	5	2 J	5
P3S	U	5	1 J	5	2 J	5
P3S-DUP	U	5	U	5	2 J	5
P3D	11	5	24	5	70	5
P4S	U	5	1 J	5	2 J	5
P4M	U	5	1 J	5	1 J	5
P4D	U	5	U	5	U	5
P5S	U	5	U	5	2 J	5
P5M	U	5	1 J	5	U	5
P5D	U	5	U	5	1 J	5
P6S	U	5	1 J	5	1 J	5
P6M	U	5	2 J	5	2 J	5
P6D	U	5	1 J	5	U	5

Table A-1. Results of July 1998 Sampling at Dover Funnel & Gate Site: Organic Analytes, Chlorinated Solvents (μg/L) (Battelle Results-Draft) (Continued)

Well ID	*cis*-1,2-DCE Results	*cis*-1,2-DCE Detection Limit	TCE Results	TCE Detection Limit	PCE Results	PCE Detection Limit
P6D-DUP	U	5	1 J	5	U	5
P7S	U	5	U	5	1 J	5
P7D	U	5	U	5	U	5
P8S	U	5	U	5	2 J	5
P8D	U	5	1 J	5	1 J	5
P9S	U	5	1 J	5	1 J	5
P9D	3 J	5	3 J	5	4 J	5
P10S	U	5	1 J	5	1 J	5
P11S	U	5	1 J	5	2 J	5
P11D	U	5	1 J	5	U	5
P12S	U	5	U	5	1 J	5
P12D	U	5	1 J	5	2 J	5
P12D-DUP	U	5	1 J	5	1 J	5
P13S	U	5	2 J	5	3 J	5
P13D	U	5	U	5	U	5
P14S	U	5	1 J	5	2 J	5
P14D	3 J	5	4 J	5	4 J	5
Gate 2 Side Downgradient Aquifer Wells						
D7S	U	5	10	5	4 J	5
D7D	9	5	4 J	5	4 J	5
Existing Wells						
214S	16	5	17	5	1923	5
214D	95	5	95	5	10	5

All units are μg/L.
J: Estimated Value.
U: Below Detection Limit.

Table A-2. Dover Funnel & Gate Area 5 Site: Field Parameters July 1998 (Draft)

Well ID	pH	ORP (mv)	Eh (mv)	DO (mg/L)	Water Temp (°C)	Conductivity (mS/cm)
Gate 1 Side Upgradient Wells						
U1S	4.81	78.0	275.0	6.16	26.14	0.267
U2S	4.81	59.2	256.2	4.92	24.22	0.121
U3S	4.99	41.9	238.9	3.01	23.95	0.278
U3D	4.63	32.1	229.1	1.38	23.22	0.187
U4S	5.52	-40.3	156.7	2.14	26.91	0.337
U4M	4.62	65.6	262.6	6.09	23.71	0.170
U4D	4.69	72.4	269.4	5.32	24.88	0.185
U5S	5.19	72.7	269.7	3.99	21.89	0.236
U5D	5.46	71.9	268.9	0.86	21.35	0.433
U6S	5.02	117.9	314.9	6.26	22.65	0.103
U10S	4.95	109.5	306.5	4.04	22.17	0.137
U11S	4.83	117.6	314.6	4.47	22.70	0.113
U12S	4.67	123.4	320.4	2.69	23.46	0.157
U13S	4.81	89.5	286.5	4.21	23.09	0.275
U14S	4.97	88.6	285.6	5.29	23.71	0.348
U15S	4.80	77.5	274.5	2.64	23.18	0.259
U16S	4.76	81.6	278.6	4.07	24.19	0.113
U17S	4.74	84.2	281.2	4.61	23.71	0.186
U18S	4.86	44.6	241.6	1.97	23.05	0.262
Gate 1 Pre-Treatment Zone Wells						
F1S	10.33	-366.1	-169.1	0.23	26.89	0.233
F2S	10.35	-443.1	-246.1	0.25	26.87	0.233
F2M	10.28	-462.2	-265.2	0.45	23.76	0.142
F2D	10.18	-447.4	-250.4	0.22	23.50	0.151
F3S	10.45	-449.9	-252.9	0.50	28.89	0.242
F3D	10.42	-491.9	-294.9	0.30	24.48	0.170
Gate 1 Reactive Barrier Cell Wells						
F4S	10.54	-492.8	-295.8	0.37	27.33	0.271
F4M	10.51	-474.5	-277.5	0.46	24.78	0.155
F4D	10.75	-467.2	-270.2	0.34	23.12	0.164
F5M	10.63	-474.3	-277.3	0.45	24.49	0.173
F5D	10.69	-492.8	-295.8	0.47	23.47	0.203
F5S	10.49	-481.3	-284.3	0.27	26.84	0.280
F6S	10.64	-496.6	-299.6	0.34	25.36	0.249
F6M	10.64	-486.4	-289.4	0.25	23.89	0.205
F6D	10.79	-481.0	-284.0	0.32	27.09	0.228
F7S	10.45	-488.3	-291.3	0.21	26.31	0.266
F7D	10.71	-481.8	-284.8	0.33	24.69	0.214
F8S	10.59	-465.3	-268.3	0.41	23.81	0.268
F8D	10.66	-476.2	-279.2	0.46	22.93	0.200
F9S	10.57	-466.6	-269.6	0.36	23.83	0.233
F9D	10.63	-480.1	-283.1	0.46	21.74	0.213
F10	10.78	-462.8	-265.8	0.29	22.71	0.278
F11S	10.54	-448.2	-251.2	0.19	26.53	0.287

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Table A-2. Dover Funnel & Gate Area 5 Site: Field Parameters July 1998 (Draft) (Continued)

Well ID	pH	ORP (mv)	Eh (mv)	DO (mg/L)	Water Temp (°C)	Conductivity (mS/cm)
F11D	10.57	-468.2	-271.2	0.50	27.11	0.272
F12S	10.62	-447.6	-250.6	0.37	25.66	0.269
F12D	10.60	-471.9	-274.9	0.56	21.73	0.216
Gate 1 Downgradient Sand Wells						
F13S	10.11	-206.6	-9.6	0.59	22.46	0.261
F13D	10.77	-451.1	-254.1	0.70	21.54	0.242
F14S	10.09	-295.8	-98.8	0.27	26.95	0.231
F14D	10.48	-483.9	-286.9	0.89	25.53	0.248
Gate 1 Side Downgradient Aquifer Wells						
D1S	5.02	71.1	268.1	6.44	24.56	0.389
D2S	4.81	19.1	216.1	1.05	24.32	0.429
D3S	4.88	48.8	245.8	3.52	24.74	0.286
D4S	5.41	50.2	247.2	0.74	24.59	0.282
D5S	5.54	-45.4	151.6	1.71	27.72	0.558
D5D	5.87	-70.3	126.7	0.60	26.23	0.242
D6S	5.80	35.6	232.6	0.65	23.84	0.354
Gate 2 Upgradient Aquifer Wells						
U7S	5.08	60.5	257.5	0.89	21.73	0.247
U7D	5.17	73.8	270.8	0.73	20.64	0.311
U8S	6.07	-44.0	153.0	0.26	22.55	0.408
U8M	6.27	0.9	197.9	0.49	22.33	0.275
U8D	6.12	-28.5	168.5	0.92	23.92	0.320
U9S	5.45	1.8	198.8	0.50	21.04	0.203
U9D	4.72	95.2	292.2	3.62	21.84	0.195
Gate 2 Pre-Treatment Zone Wells						
P1S	7.98	-293.5	-96.5	0.25	28.72	0.470
P1S-2	8.78	-228.9	-31.9	0.26	23.74	0.485
P2S	11.39	-334.9	-137.9	0.05	25.84	0.864
P2S-2	11.52	-349.3	-152.3	0.45	23.96	0.798
P2M	10.90	-420.5	-223.5	0.50	24.63	0.353
P2D	10.72	-384.6	-187.6	0.32	23.98	0.302
P2D-2	10.60	-375.4	-178.4	0.50	22.52	0.314
P3S	11.52	-394.4	-197.4	0.08	26.40	0.931
P3S-2	11.55	-404.6	-207.6	0.46	24.14	0.857
P3D	9.92	-292.2	-95.2	0.27	23.41	0.274
Gate 2 Reactive Barrier Cell Wells						
P4S	11.76	-397.8	-200.8	0.27	24.62	1.255
P4M	11.21	-408.0	-211.0	0.51	25.04	0.519
P4D	11.07	-462.4	-265.4	0.12	22.24	0.332
P5S	11.38	-401.0	-204.0	0.18	26.55	0.830
P5M	10.68	-407.5	-210.5	0.50	24.51	0.325
P5D	10.89	-450.6	-253.6	0.12	25.02	0.348
P6S	11.60	-410.9	-213.9	0.05	27.97	0.725
P6M	10.54	-403.7	-206.7	0.53	24.98	0.338
P6D	10.72	-420.9	-223.9	0.39	22.85	0.337

Table A-2. Dover Funnel & Gate Area 5 Site: Field Parameters July 1998 (Draft) (Continued)

Well ID	pH	ORP (mv)	Eh (mv)	DO (mg/L)	Water Temp (°C)	Conductivity (mS/cm)
P7S	11.21	-401.4	-204.4	0.27	24.45	0.688
P7D	10.97	-424.8	-227.8	0.39	22.45	0.361
P8S	11.44	-413.2	-216.2	0.49	24.29	0.760
P8D[1)]	10.79	-421.7	-224.7	0.49	25.80	0.348
P9S	11.17	-403.0	-206.0	0.50	24.65	0.551
P9D	10.83	-427.2	-230.2	0.65	22.94	0.360
P10	10.96	-427.5	-230.5	0.37	22.99	0.410
P11S	10.69	-399.5	-202.5	0.29	25.09	0.487
P11D	11.14	-425.1	-228.1	-0.22	26.26	0.418
P12S	10.88	-418.4	-221.4	0.21	23.63	0.418
P12D	10.86	-434.9	-237.9	0.58	23.17	0.379
P13S	11.04	-399.5	-202.5	0.44	23.92	0.509
P13D	10.53	-385.0	-188.0	0.57	22.79	0.327
P14S	10.80	-401.4	-204.4	0.11	25.06	0.443
P14D	10.56	-380.3	-183.3	0.06	22.50	0.323
Gate 2 Downgradient Aquifer Wells						
D7S	9.63	-171.4	25.6	0.28	27.89	0.421
D7D	9.82	-203.1	-6.1	0.32	22.91	0.309
Existing Wells						
214S	4.37	238.1	435.1	4.07	24.43	0.119
214D	4.70	1.8	198.8	1.36	34.11	NA

1) P8D field parameters are measured from medium well depth.

Table A-3. Results of July 1998 Sampling at Dover Funnel & Gate Site: Inorganic Analytes (mg/L) (Draft)

Well ID	Alkalinity		Calcium		Chloride		Iron		Magnesium		Manganese	
	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit
Gate 1 Side Upgradient Aquifer Wells												
U4S	13	1	16.4	0.2	39	1	U	0.03	14.5	0.2	0.03	0.02
U4D	4	1	4.9	0.2	20	1	U	0.03	4.8	0.2	0.12	0.02
Gate 1 Wells												
F1S	32	1	8.9	0.2	11	1	0.04	0.03	U	0.2	U	0.02
F2S	34	1	6	0.2	18	1	U	0.03	U	0.2	U	0.02
F2D	46	1	3.43	0.2	21	1	0.05	0.03	0.48	0.2	U	0.02
F3S	35	1	4.6	0.2	15	1	0.05	0.03	U	0.2	U	0.02
F3D	46	1	2.42	0.2	20	1	0.04	0.03	U	0.2	U	0.02
F4S	38	1	7.6	0.2	18	1	0.08	0.03	U	0.2	U	0.02
F4D	35	1	6.6	0.2	21	1	0.05	0.03	U	0.2	U	0.02
F5S	37	1	12.2	0.2	19	1	0.04	0.03	U	0.2	U	0.02
F5D	29	1	5.2	0.2	24	1	U	0.03	U	0.2	U	0.02
F6S	40	1	5.9	0.2	12	1	U	0.03	U	0.2	U	0.02
F6D	39	1	3.83	0.2	18	1	U	0.03	U	0.2	U	0.02
F7S	41	1	12.2	0.2	22	1	0.06	0.03	U	0.2	U	0.02
F7D	35	1	7.5	0.2	25	1	0.07	0.03	U	0.2	U	0.02
F11S	54	1	6	0.2	28	1	0.07	0.03	U	0.2	U	0.02
F11D	53	1	10.3	0.2	24	1	U	0.03	U	0.2	U	0.02
F12S	58	1	3.46	0.2	16	1	0.06	0.03	U	0.2	U	0.02
F14S	58	1	4.56	0.2	13	1	0.11	0.03	U	0.2	U	0.02
F14D	36	1	6	0.2	26	1	U	0.03	U	0.2	U	0.02
Gate 1 Side Downgradient Aquifer Wells												
D5S	13	1	47.1	0.2	30	1	0.04	0.03	20.3	0.2	0.06	0.02
D5D	28	1	6.2	0.2	43	1	0.22	0.03	1.16	0.2	0.35	0.02
Gate 2 Side Upgradient Aquifer Wells												
U8S	30	1	21.3	2	59	1	0.05	0.03	8.7	2	0.31	0.02
U8D	54	1	9.2	2	26	1	0.04	0.03	4.99	0.2	0.65	0.02
Gate 2 Wells												
P1S	59	1	31.1	0.2	41	1	0.49	0.03	4.61	0.2	0.15	0.02

Table A-3. Results of July 1998 Sampling at Dover Funnel & Gate Site: Inorganic Analytes (mg/L) (Draft) (Continued)

Well ID	Alkalinity		Calcium		Chloride		Iron		Magnesium		Manganese	
	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit
P2S	180	1	44.3	2	27	1	0.18	0.03	U	0.2	U	0.02
P2D	42	1	8.9	0.2	18	1	U	0.03	U	0.2	U	0.02
P3S	185	1	66	2	20	1	0.05	0.03	U	0.2	U	0.02
P3D	94	1	13.2	0.2	19	1	0.07	0.03	1.12	0.2	0.08	0.02
P4S	265	1	63	0.2	21	1	0.07	0.03	U	0.2	U	0.02
P4D	87	1	2.84	0.2	20	1	0.07	0.03	U	0.2	U	0.02
P5S	150	1	50	2	24	1	0.04	0.03	U	0.2	U	0.02
P5D	79	1	3.37	0.2	23	1	U	0.03	U	0.2	U	0.02
P6S	134	1	45.7	0.2	31	1	U	0.03	U	0.2	U	0.02
P6D	79	1	7.2	2	30	1	0.04	0.03	U	0.2	U	0.02
P7S	133	1	14.8	0.2	14	1	U	0.03	1.5	0.2	U	0.02
P7D	81	1	4.25	0.2	24	1	U	0.03	U	0.2	U	0.02
P11S	73	1	97	2	37	1	U	0.03	U	0.2	U	0.02
P11D	75	1	45.7	0.2	29	1	U	0.03	U	0.2	U	0.02
P12S	66	1	12	0.2	27	1	U	0.03	U	0.2	U	0.02
P12S-DUP	66	1	10.8	0.2	32	1	U	0.03	U	0.2	U	0.02
P14S	82	1	5.3	2	26	1	U	0.03	U	0.2	U	0.02
P14D	92	1	4.65	0.2	22	1	0.18	0.03	U	0.2	U	0.02
Gate 2 Side Downgradient Aquifer Wells												
D7S	137	1	16.3	2	20	1	0.11	0.03	U	0.2	U	0.02
D7S-DUP	134	1	10.6	0.2	12	1	NA	NA	1.52	0.2	U	0.02
D7D	112	1	5.3	2	23	1	0.11	0.03	U	0.2	U	0.02
Existing Wells												
214S	2	1	3.18	0.2	16	1	U	0.03	3.75	0.2	0.08	0.02
214D	7	1	3.13	0.2	22	1	U	0.03	2.75	0.2	0.05	0.02

Table A-3. Results of July 1998 Sampling at Dover Funnel & Gate: Inorganic Analytes (mg/L) (Draft) (Continued)

Well ID	Nitrate		Silica		Sodium		Sulfate		TDS	
	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit
Gate 1 Side Upgradient Aquifer Wells										
U4S	6.84	1	4.67	2	14.5	0.2	53	5	244	10
U4D	11	1	10.2	2	16.6	0.2	12	5	142	10
Gate 1 Wells										
F1S	0.03	0.02	U	2	23.2	0.2	28	5	128	10
F2S	U	0.02	U	2	27	0.2	31	5	128	10
F2D	0.08	0.02	U	2	23.3	0.2	U	5	94	10
F3S	U	0.02	U	2	26.5	0.2	32	5	112	10
F3D	U	0.02	U	2	25.9	0.2	U	5	100	10
F4S	U	0.02	U	2	31	0.2	39	5	138	10
F4D	U	0.02	U	2	19	0.2	U	5	82	10
F5S	U	0.02	U	2	30	0.2	44	5	160	10
F5D	U	0.02	U	2	24.5	0.2	15	5	94	10
F6S	U	0.02	U	2	25.4	0.2	35	5	126	10
F6D	0.08	0.02	U	2	27.3	0.2	18	5	116	10
F7S	U	0.02	U	2	25.1	0.2	35	5	136	10
F7D	U	0.02	U	2	24	0.2	24	5	118	10
F11S	U	0.02	U	2	38.5	0.2	22	5	154	10
F11D	U	0.02	U	2	35.5	0.2	19	5	148	10
F12S	U	0.02	2.39	2	40.4	0.2	31	5	142	10
F14S	U	0.02	5.27	2	37.5	0.2	22	5	154	10
F14D	U	0.02	3.01	2	31	0.2	22	5	156	10
Gate 1 Side Downgradient Aquifer Wells										
D5S	23.1	2	4.69	2	13.9	0.2	94	10	418	10
D5D	0.16	0.02	9.95	2	38.9	0.2	24	5	154	10
Gate 2 Side Upgradient Aquifer Wells										
U8S	2.75	0.2	11.7	2	47.9	2	71	5	278	10
U8D	2.89	0.2	9.42	2	44.9	2	61	5	210	10
Gate 2 Wells										
P1S	U	0.02	8.78	2	40.2	0.2	84	10	282	10

Table A-3. Results of July 1998 Sampling at Dover Funnel & Gate: Inorganic Analytes (mg/L) (Draft) (Continued)

Well ID	Nitrate		Silica		Sodium		Sulfate		TDS	
	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit	Results	Detection Limit
P2S	0.05	0.02	8.26	2	27.5	2	41	5	324	10
P2D	U	0.02	U	2	34.6	0.2	53	5	186	10
P3S	0.02	0.02	6.14	2	23.3	2	53	5	350	10
P3D	U	0.02	4.65	100	34.7	0.2	26	5	188	10
P4S	0.02	0.02	3.77	2	22.2	0.2	35	5	400	10
P4D	U	0.02	U	2	45.4	2	15	5	228	10
P5S	0.02	0.02	3.87	2	26.6	2	35	5	288	10
P5D	0.03	0.02	U	2	42.3	2	21	5	254	10
P6S	U	0.02	3.11	2	21.9	0.2	52	5	268	10
P6D	U	0.02	U	2	44.1	2	18	5	240	10
P7S	0.06	0.02	4.74	2	47.7	0.2	46	5	288	10
P7D	U	0.02	U	2	40.9	0.2	29	5	228	30
P11S	U	0.02	U	2	48.7	2	71	5	336	10
P11D	U	0.02	U	2	39.2	0.2	37	5	234	10
P12S	0.02	0.02	U	2	39.1	0.2	62	5	248	10
P12S-DUP	U	0.02	U	2	39.6	0.2	66	5	256	10
P14S	U	0.02	3.38	2	48	2	61	5	300	10
P14D	U	0.02	5.19	2	44.8	0.2	23	5	256	10
Gate 2 Side Downgradient Aquifer Wells										
D7S	U	0.02	U	2	29.7	2	23	5	266	10
D7S-DUP	0.06	0.02	4.82	2	47.2	0.2	45	5	290	10
D7D	U	0.02	8	2	48.3	2	8	5	266	10
Existing Wells										
214S	4.54	1	10.8	100	8.7	0.2	U	5	90	10
214D	3.57	0.5	10.8	100	12.3	0.2	U	5	102	10

NA: Not Available.
All Units are mg/L.
U: Below Detection limit.
J: Estimated value.